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NEW FLIGHT DISPLAY FORMATS

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ABSTRACT

Electro-mechanical (E-M) instruments, which have been associated with aircraft cockpits since World War I, are rapidly being replaced by electro-optical instruments in both military and civilian aircraft. As the conversion continues, questions arise as to the impact of these displays on the pilot's efficiency. One of the most important issues of the modern cockpit centers around the pilot-computer interface -- that is, are the display's graphic formats, which have replaced the tried and true E-M instruments, intuitive? This paper describes three new ways to present flight information to the pilot on head down and head up displays and discusses research results geared toward answering this question.

INTRODUCTION

Rapid developments in display technology are dramatically affecting cockpit design. Beginning with the F-18 and continuing through the F-15E, cockpits have changed from presenting information on mostly electro-mechanical (E-M) instruments to utilizing electro-optical (E-O) displays for the presentation of information required by the pilot. Additionally, the function of the head up display (HUD) has vastly changed over the years. What was once a dynamic bomb sight has evolved into a highly complex display presenting flight critical information in addition to weapon delivery symbology. As the conversion continues, questions arise as to the pilot's efficiency with this equipment. Initial indications are that pilots perform quite well with the new equipment; however, the display formats are first generation – reproductions of E-M instruments, such as the attitude director indicator (ADI). How well will the pilots interact with the second generation display formats? The objective of this paper is to discuss recent research in the area of new head down and head up cockpit flight display formats, specifically a Background Attitude Indicator, a Pathway HUD Format, and a baseline Military Standard HUD.

A NEW HEAD DOWN FLIGHT DISPLAY FORMAT

The Evolution of the Background Attitude Indicator

The principle goal of the Background Attitude Indicator (BAI) format is maintaining flight safety when there is no dedicated head down primary attitude indicator. With limited display space, designers have decreased the size of the ADI and moved it out of the primary viewing area. The HUD would be used as the primary flight display with no dedicated head down primary attitude indicator. Loss of attitude awareness (a potential flight safety problem) could result.

This problem was initially investigated by researchers at Lockheed Ft. Worth (Spengler, 1988) who created a BAI using only a 3/4 inch electronic border around the outer edge of the display (Figure 1). The three displays on the front instrument panel have the central rectangular portion of each format presenting mission related information, and the background border presenting a single attitude display format which extended across <u>all</u> <u>three</u> displays (Figure 2). The attitude information, in essence, framed the mission essential display format and acted as one large attitude indicator. The BAI consisted of a white horizon line with blue above it to represent positive pitch, and brown below it to represent negative pitch. This display worked very well for detecting deviations in roll, but was less successful in showing deviations in pitch because, once the horizon line left the pilot's field of view, the only attitude information present in the BAI was solid blue (sky) or brown (ground). Because the concept was effective in showing roll deviations but lacked in the pitch axis, enhancing the pitch axis became the focus of the work done in Wright Laboratory's Advanced Cockpit Branch.

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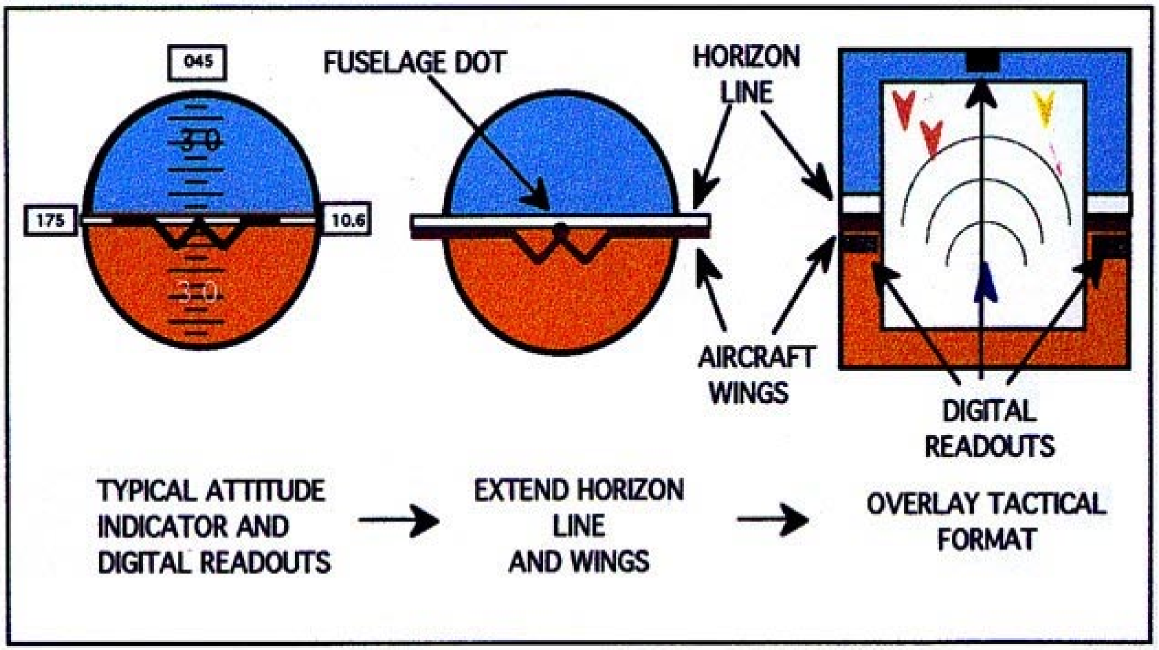

Figure 1. Evolution from ADI to BAI.

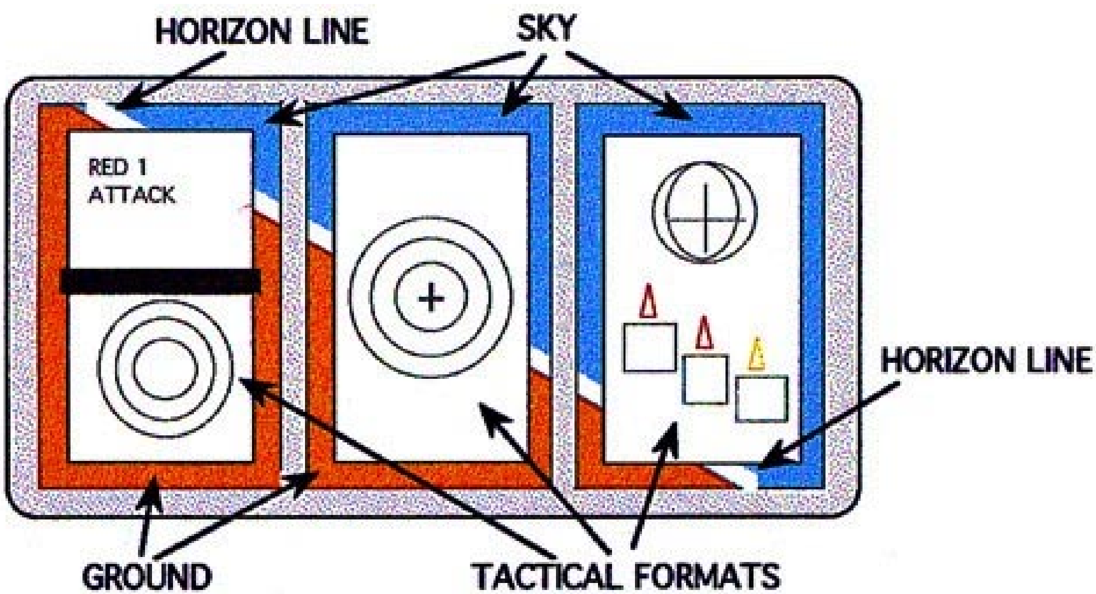

Figure 2. Spengler background attitude indicator (Ref. Spengler).

Wright Lab BAI Research - Part 1

The Lab's initial work began by enhancing the pitch cues for a BAI, which framed one display format only (as opposed to framing three display formats as in the original Lockheed work) (Liggett, Reising, & Hartsock, 1992). Eight variations of the BAI were evaluated, and they each contained the following common elements: 1) digital readouts of airspeed, altitude, and heading; 2) wing reference lines to provide an attitude reference (extensions of the normal miniature aircraft wings); and 3) the ghost horizon (a dashed white line that appeared when the true horizon left the pilot's field of view, and that indicated the direction of the true horizon) (Figure 3). This configuration was tested alone, as well as with the additions of color shading (the lightest shade of blue or brown appeared at the horizon and became gradually darker as positive or negative pitch increased to 90^{o}), color patterns (a vertical wedge with the thinnest portion at the horizon and the thickest portion at the zenith or nadir), and pitch lines with numbers. These design features were compared individually, in combinations of two, and with all three present.

To determine if effective pitch information was being portrayed, the Wright Lab study simulated the task of recovering from unusual attitudes. This determined if adequate pitch information was present since pitch information is a key factor in a successful recovery.

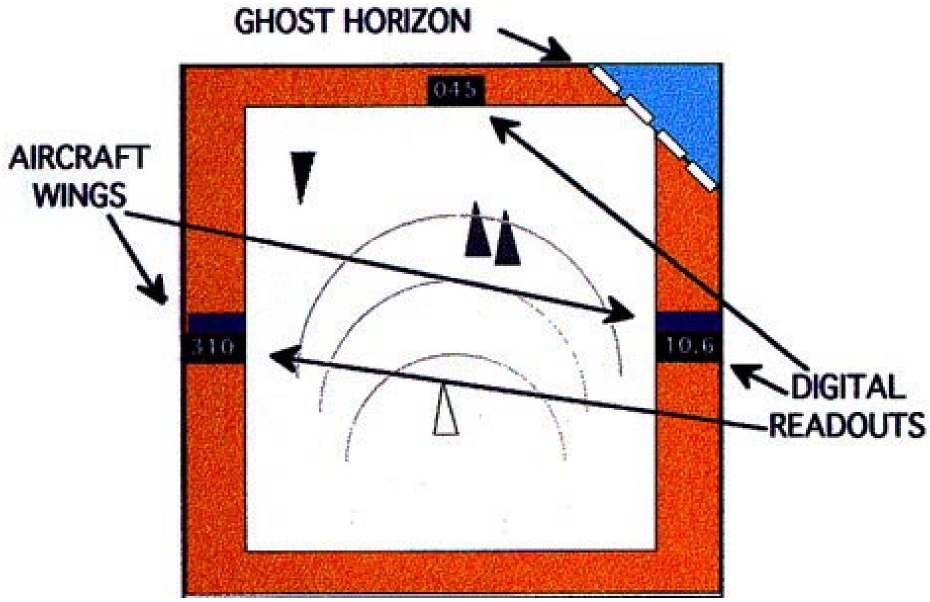

Figure 3. Digital readouts, wings, and ghost horizon (plane is in a 45° roll, negative pitch).

Results of BAI Part 1

Results showed that the combination of color shading and color patterns (Figure 4) was the format that had the quickest initial stick input time. When using this format, the pilots moved the control stick to begin their recoveries more quickly than when using any other format. This measure of initial stick input time related to the interpretability of the format because the pilots looked at the format, determined their attitude via the cues on the BAI, and began their recovery as quickly as possible.

Wright Lab BAI Research - Part 2

Because progress was made in the initial work by successfully portraying pitch information to allow the pilots to recover from unusual attitudes, a second study followed. Recall that the original Lockheed work looked at portraying a BAI for all three displays on the front instrument panel. This follow-on research incorporated a similar configuration of Lockheed's three horizontally adjacent head down displays of the same dimensions, but also included the most effective pitch cues from the initial investigation.

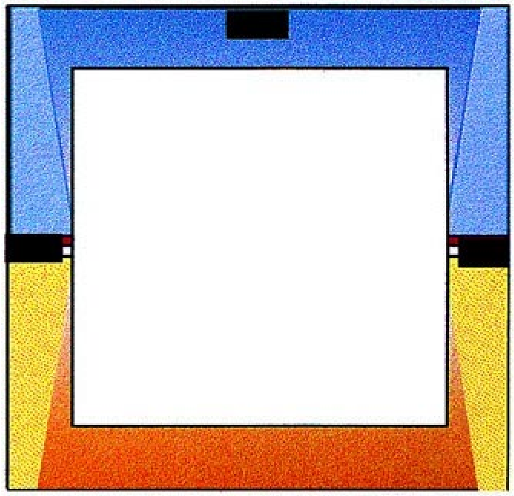

Figure 4. Color shading and patterns.

The BAI formats investigated were of two types, “Triplets” and “Global”. The Triplets format consisted of each of the three displays presenting individual, identical attitude information (Figure 5). Each display acted as a single, independent attitude indicator. Because the pilot could be focusing on the information from any of the three display

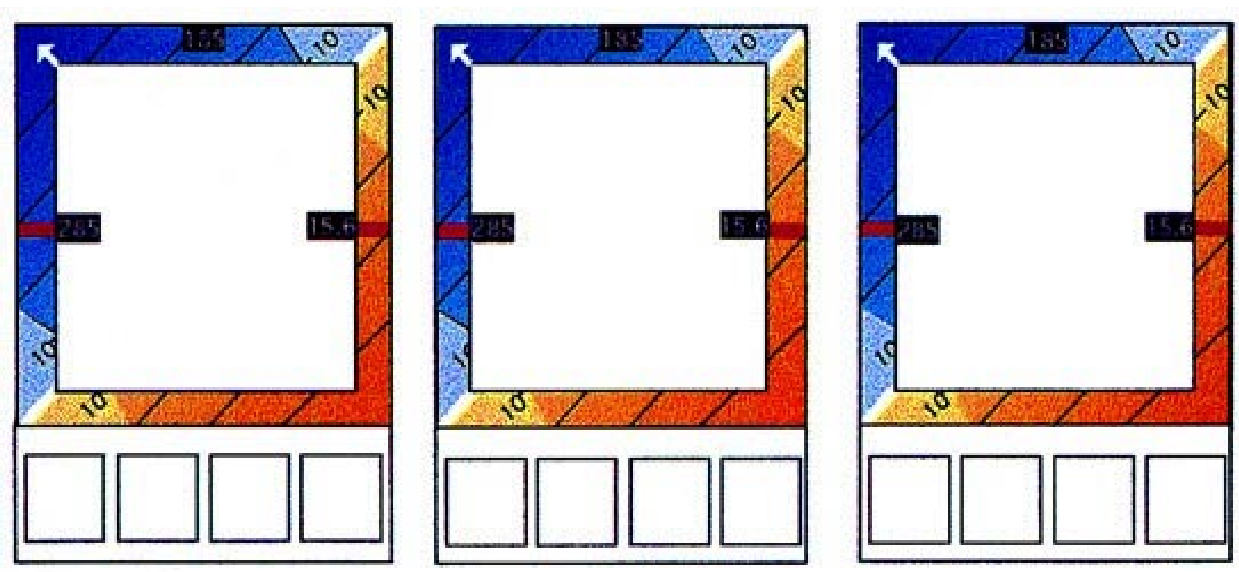

Figure 5. Triplet format.

formats at a given time, it was thought that being able to interpret the aircraft's attitude from using just the information from that specific BAI may be beneficial. The Global format consisted of all three horizontally adjacent BAIs acting as one large attitude indicator as in the original Lockheed study (Figure 6). It was anticipated that using the global BAI would be similar to seeing the outside world in its entirety, and thus, provide a benefit to the pilot. The Triplets and the Global formats had the same common elements of digital readouts, wing reference lines, a ghost horizon, and sky pointers. The pitch cues used were of two styles: 1) color shading and color patterns (the best format from the previous research), and 2) color shading, color patterns, and pitch lines with numbers. Although the

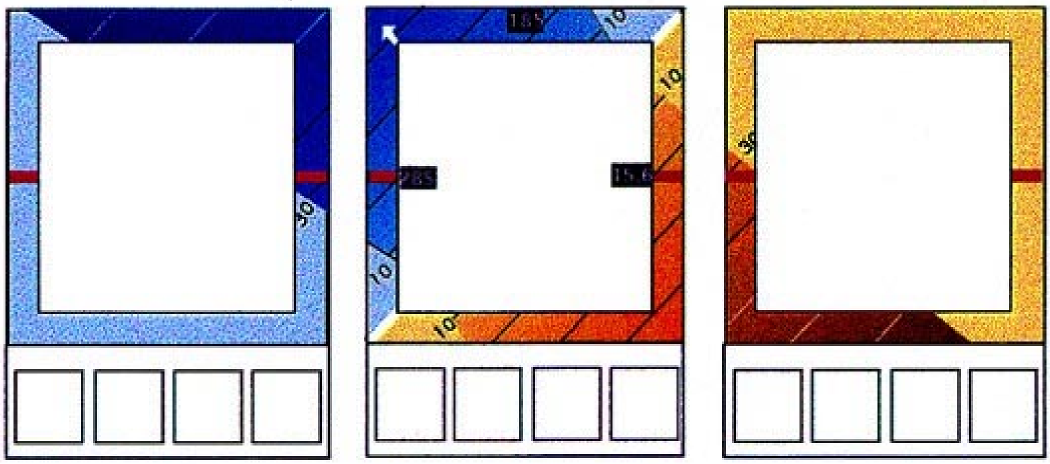

Figure 6. Global format.

second format was not considered the most beneficial from the previous research, the pilots expressed a unanimous opinion that they would prefer to include the pitch lines with numbers on their BAI.

Results of BAI Part 2

Objective results were inconclusive; however, subjective results revealed that the pilots highly favored the global formats that provided color shading, color patterns, and pitch lines with number references. Thirteen of sixteen subjects ranked this type of format highest. The global aspect tended to give the pilots excellent peripheral bank cues, while the combination of shaded patterns and pitch lines with numbers gave both qualitative and quantitative pitch reference, as well as pitch rate information. The Triplet format was rated low because the individual formats tended to distract the pilot with each BAI moving separately and displaying identical yet independent attitude information. The pilots were inclined to use only the center multi-function display for attitude information and completely ignore the two outboard displays.

Conclusions of BAI Research

Based on the results of these simulation studies, background attitude indicators appear to be a viable means of enabling the pilot to recover from unusual attitudes. A single background attitude indicator works best with visual cues (such as color shading and color patterns) that can use the flow patterns, which enable the pilot to detect motion quickly, while not requiring the high visual acuity required for reading. When using multiple displays to show attitude information, pilots preferred having a global BAI that presents peripheral banking cues. The combination of color shading, color patterns, and pitch lines with numbers provided both exact and generalized pitch information. The pitch line with numbers allowed the pilot to make an exact, quantitative assessment of attitude, while the color shading and the amount of the pattern showing gave the pilot quick glance qualitative orientation information.

The underlying technology, E-O displays and advanced computer graphics processors, which has made the BAI possible on head down displays, has also enabled the crewstation designer to create new HUD formats.

NEW HEAD UP DISPLAY FORMATS

The Evolution of the Military Standard HUD Format

Because of the HUD's location in the cockpit, it was an optimum display for presenting weapon delivery symbology. With the advent of sophisticated graphics generators, the symbology sets on the HUD have changed from a focus on only tactical operations to also including basic flight control and performance operations. Each symbology set developed tried to depict all the information necessary for primary flight; however, some fell short. Additionally, there was no easy transition between one HUD-equipped aircraft and another because of the numerous symbology sets. These factors contributed to the task of developing a standardized HUD symbology set for use during instrument flight. The set would "serve as a baseline format from which unique HUD formats would be developed for different aircraft types and mission requirements" (Bailey & Ohmit, 1991, p. 1). The following description is the baseline HUD format symbology set.

Baseline Military Standard HUD (MS-HUD) Format Description

Some of the symbols in baseline MS-HUD format were changed from the "old standard" (Figure 7). To illustrate, the airspeed indicator and altimeter had circular scales, similar to analog instruments, instead of the tape readouts used in other HUDs. Aircraft reference symbology included a flight path marker, a climb-dive angle marker, a climb-dive scale, an acceleration cue, and a speed worm. The format also contained attitude and instrument landing symbology such as a course deviation indicator (CDI) to display the intended course. Additionally, it also incorporated standard pitch and bank steering bar symbols, similar to those used in other HUDs and ADIs, to command flight toward the intended course and glide path. A complete description of military HUD symbology can be found in MIL-STD-1787B (Draft) Aircraft Display Symbology (In Press).

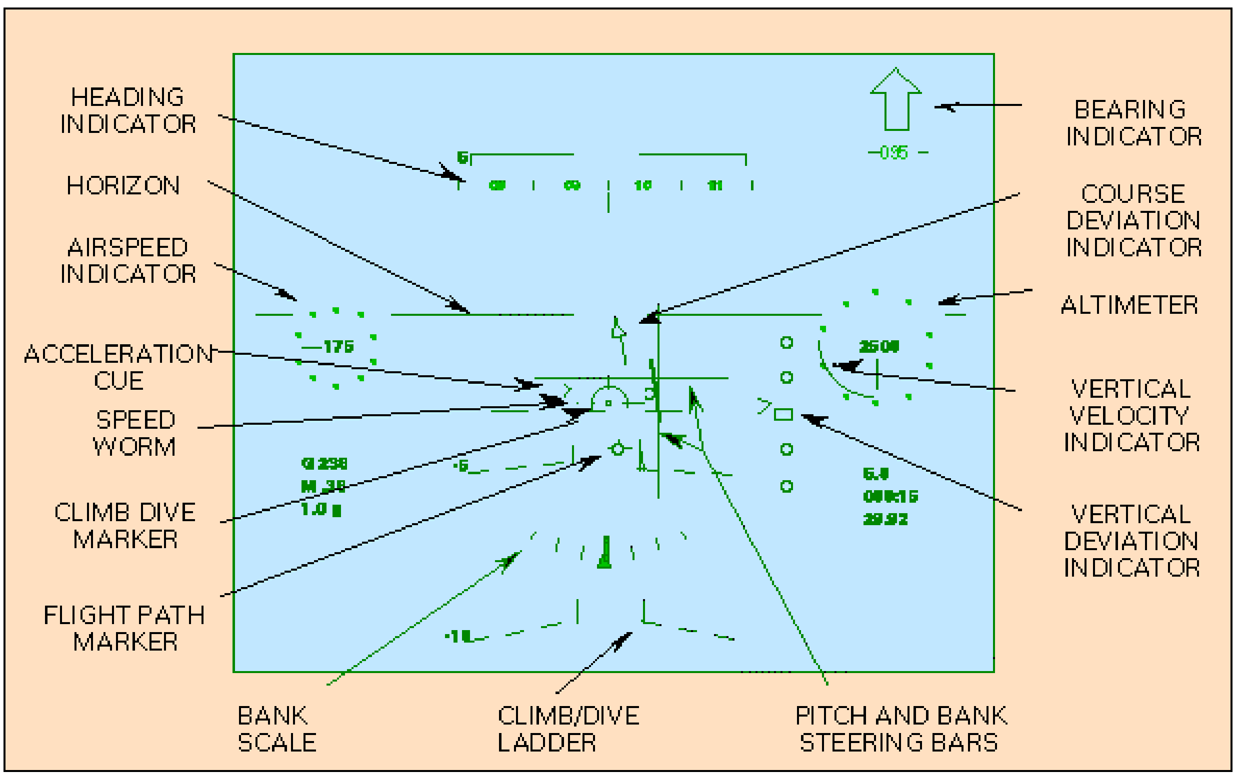

Figure 7. Military Standard HUD format.

The Evolution of the Pathway HUD Format

The concept of using pathways to assist pilots in anticipating upcoming flight paths was first formulated and defined in the early 1950s through the Army-Navy Instrumentation Program. It was further advanced in the 1970s when Northrop conducted internal research and development and was subsequently awarded a contract by the Naval Air Development Center to demonstrate their flight path approach (Watler & Logan, 1981). Over the next two decades, the pathway concept was examined by the Naval Air Warfare Center in Warminster, Pennsylvania. The Center's primary goal was to develop predictive pathway symbology to aid pilots in navigating to the target and performing carrier landings. USAF researchers at Wright Laboratory had been following these tests since the early Navy trials and had even conducted pilot-in-the-loop simulation tests to ascertain if the pathway could be used to recover from unusual altitudes (Reising, Barthelemy, & Hartsock, 1991). When the Global Positioning System’s satellites became available, and the issue of curved approaches arose, the pathway seemed an ideal method of depicting these complex approaches to the pilot.

Pathway HUD Format Description

This format used a "highway" to display the intended route of flight. The highway was made up of a continuous string of path blocks drawn in perspective, representing 45 seconds of flight into the future (Figure 8). The format incorporated a velocity index displayed in the shape of a small aircraft, called the follow-me aircraft. The follow-me aircraft was drawn to fly along the left side of the pathway at an altitude equal to 150 feet above the desired altitude. It always flew a perfect position along the commanded path at the correct airspeed. To fly the commanded path displayed by the symbology, the pilots only needed to fly in an echelon formation on the right wing of the follow-me aircraft. This placed the pilots approximately on the centerline of the course. When flying on-speed, it appeared to the pilots that they were one block behind the follow-me aircraft. When the follow-me aircraft moved away from them, it denoted that they were flying too slow, and when it moved back toward them, it indicated that they were flying too fast.

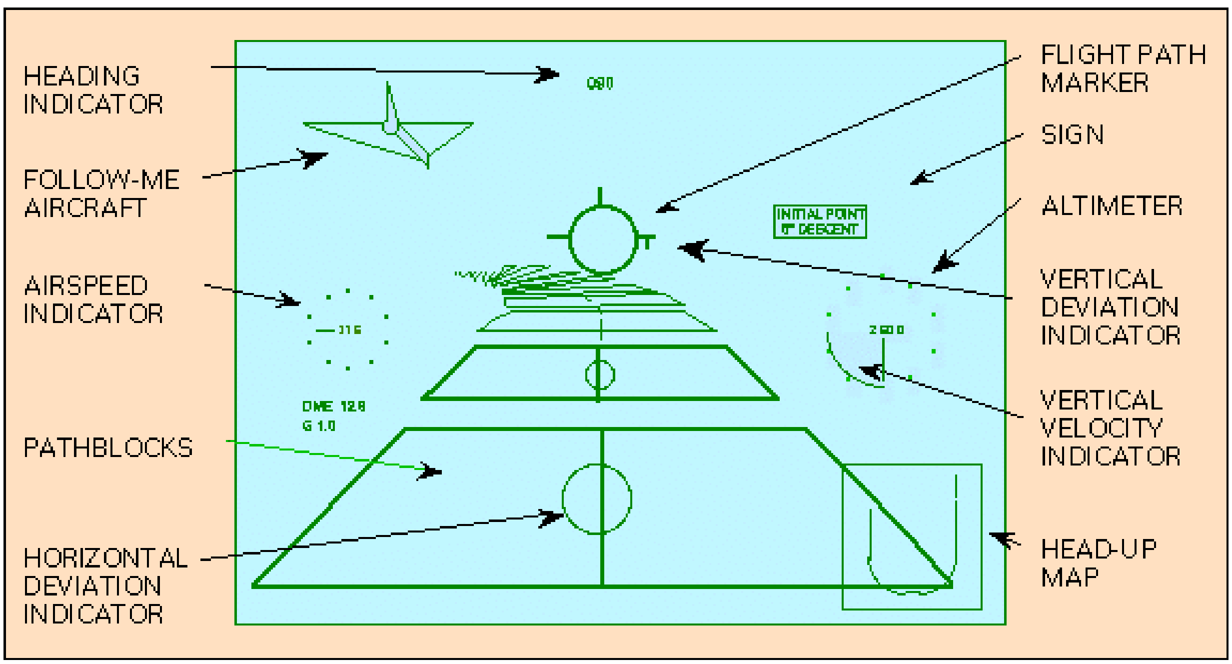

Figure 8. Pathway format.

The pilots could obtain anticipatory attitude cues by observing both the maneuvers of the follow-me aircraft and the path blocks. For example, if the follow-me aircraft rotated slightly downward about its pitch axis, the pilot could anticipate the need for a descent to remain on the desired flight path. The aircraft's actual position in relation to the course centerline was shown by the use of small circles drawn on the pathway. These horizontal deviation indicators showed real time deviation from the centerline and correlated to the dot deviations of a standard CDI. The empty deviation circle on the path block would become half full as one dot of course deviation was reached and

become completely full at two dots deviation (at the extreme left or right edge of the path block). Corrections were made by the pilot turning either left or right, as needed.

Vertical deviation from the published altitude or glide slope was shown as a "worm" growing from the right wing of the flight path marker. The worm directly correlated to the dot system of raw glide slope deviation symbology. If the pilot was one dot low, an empty circle was added to the end of the worm. If the pilot was two dots low, the worm continued to grow and a second solid circle appeared at the end of the worm (see Figure 8, Vertical Deviation Indication). When the pilot was low on altitude, the worm projected downward from the wing, and if too high, it grew upward. To make corrections the pilot flew the aircraft so as to push the worm back into the wing. Whenever the aircraft's pitch angle reached 30 degrees, nose up or nose down, or when the pilot lost visual sight of the path block, a horizon line with a digital pitch angle readout and a flight director symbol appeared to lead the pilot back to straight and level flight and to the pathway. "Road signs" were also used to alert the pilots to profile information such as navigation points, glide slope steepness, exact route changes, and a brief description of that change. In the bottom right-hand corner, a fixed-map, moving aircraft display was superimposed on the pathway format. It contained an ownship symbol that followed along the route.

Comparison of the Pathway HUD Format and the Baseline Military Standard HUD Format

To evaluate the usefulness of the Pathway HUD format to fly curved approaches, a study was conducted in which it was compared to the baseline MS-HUD. Since the baseline MS-HUD was designed to fly instrument landing system approaches (straight paths), the mechanization of the flight director was modified to command curved paths. Dependent measures collected for the comparison were root mean square (RMS) course deviations, RMS altitude deviations, and RMS airspeed deviations. Results showed that there was a significant performance difference between the two formats for all dependent measures -- the pathway format performed better than the standard HUD symbology in all cases.

As reported by the pilots, the primary reason for the Pathway HUD’s advantage over the baseline MS-HUD format was the pilots’ ability to see the route in the form of a highway from their present position to a point 45 seconds into the future. They could see where turns, altitude changes, and descent rate changes took place, as well as the magnitude of each, thus anticipating necessary control movements. In contrast, when the pilots used the baseline MS-HUD, they could not "see into the future" using this format by itself. They had to bring the map display into their scan or use the approach plate to determine where turns, altitude changes and descent rate changes would take place.

All pilots preferred the Pathway HUD to the baseline MS-HUD for flying curved approaches. When asked about today’s standard instrument flight rules approaches, nine of the twelve pilots thought they would perform better using the Pathway HUD over the baseline MS-HUD.

OVERALL THOUGHTS ON THE BENEFITS OF NEW COCKPIT FLIGHT DISPLAYS

The technology revolution has virtually removed the constraints on display designers, and they are limited primarily by their own creativity in providing display formats for future aircraft cockpits. It is the coupling of high resolution flat panel displays and HUDs with advanced graphics generators, that will enable the crew station designer to produce formats that will dramatically enhance the pilot's ability to obtain clear situational awareness data in the tactical arena, as well as improved flight symbology. These advanced formats will also enable pilots to "stay ahead" of their mission and allow them to act as a fast-time information processor.

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